

Towards the understanding of the impact of circular building materials and components on Occupational Health and Safety in the Construction Industry

Hacia la comprensión del impacto de los materiales y componentes circulares en la Salud y Seguridad Laboral en la Industria de la Construcción

Juan Antonio Torrecilla-García¹, Agnieszka Grazyna Skotnicka², Francisco Salguero-Caparrós³, Virginia Herrera-Pérez⁴

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Abstract

This study provides an exploratory analysis of the effects of circular materials and components on Occupational Health and Safety (OHS) within the construction industry. With circular economy (CE) principles increasingly integrated into construction, there is an emphasis on resource optimization through reuse, recycling, and waste minimization. These practices support sustainability and economic efficiency but simultaneously bring about unique occupational risks. The transition towards CE in construction necessitates an adaptive approach to safety protocols, ensuring both environmental benefits and worker safety are prioritized.

The research evaluates how circular materials such as recycled plastics, reused steel, and innovative composites introduce non-traditional hazards that may compromise worker safety if unaddressed. Traditional OHS practices require modification as these materials may exhibit unpredictable characteristics under stress or deteriorate differently than virgin materials. The potential risks range from respiratory issues due to particulate exposure during material cutting to chemical hazards from residuals in recycled content. This research argues that proactive risk management and detailed material traceability are critical for enhancing OHS in a CE framework.

The work adopts a mixed-method approach, including literature review and comparative case studies from four construction companies that integrate CE principles. Data collection incorporates interviews with project managers and OHS officers, accident report analyses, and safety audit reviews to identify safety impacts related to circular materials. Findings highlight a correlation between higher circular material usage and the need for enhanced safety measures, suggesting that comprehensive training on new material properties and risks is essential. Material traceability emerges as a pivotal factor, enabling the identification of hazardous components and facilitating the design of targeted OHS protocols.

The findings indicate that CE practices, although beneficial for the environment, introduce complexities to OHS management that require regulatory updates and innovative safety measures. Addressing these challenges would ensure that the construction sector not only meets sustainability goals but also advances worker protection in line with new material technologies. Consequently, the research underscores the importance of aligning CE strategies with robust OHS frameworks, fostering a construction industry that is both resilient and responsible. This dual commitment to sustainability and safety can enhance sectoral competitiveness, particularly in light of growing environmental regulations and resource scarcity.

Keywords: Circular economy, construction workers, circular materials, construction industry occupational health and safety.

¹ Universidad de Málaga. Email: juantorrecilla@uma.es ORCID: 0000-0002-4179-0008

² Universidad de Málaga. Email: askotnicka@uma.es ORCID: 0000-0001-5676-6687

³ Universidad de Málaga. Email: fsalguero@uma.es ORCID: 0000-0002-6261-6893

⁴ Universidad de Málaga. ORCID: 0000-0003-0085-1983

Resumen

Este trabajo examina el impacto de los materiales circulares en la Seguridad y Salud Laboral (SSL) en el sector de la construcción en España. Aunque las prácticas de economía circular (EC), como la reutilización y el reciclaje, promueven la sostenibilidad y eficiencia de costos, introducen riesgos laborales específicos que exigen protocolos de seguridad actualizados. La implementación de la EC requiere una gestión proactiva de riesgos, promoviendo un entorno de trabajo más seguro y sostenible. Este estudio destaca la importancia de comprender los materiales, aumentar la conciencia y mejorar las medidas de seguridad para maximizar los beneficios de los materiales circulares, alineando los objetivos ambientales y de seguridad ocupacional para una industria resiliente.

Palabras clave: Economía circular, construcción, materiales circulares, seguridad y salud laboral, trabajadores de la obra.

1. Introduction

The construction industry, traditionally characterized by high levels of resource consumption and waste generation, is at a critical juncture, challenged to transition towards more sustainable practices. This shift is primarily driven by the principles of the Circular Economy (CE), a model that prioritizes the reuse, recycling, and minimization of waste to extend the lifecycle of materials and reduce environmental impact. By embracing CE, the construction sector not only aligns with global sustainability goals but also fosters economic efficiency and innovation. This transformation, however, goes beyond merely adopting new materials; it requires a fundamental rethinking of how resources are managed throughout the construction lifecycle, affecting everything from initial material sourcing to end-of-life disposal.

One of the most promising aspects of CE in construction is the use of circular materials. Circular materials include recycled and reusable components, which reduce the demand for virgin resources and lower the overall environmental footprint of building projects. For instance, integrating recycled concrete, repurposed steel, and other innovative compounds not only cuts down resource extraction but also catalyzes advancements in construction techniques. These sustainable practices reflect the growing consumer and regulatory demand for “green” buildings, resulting in benefits beyond environmental gains. Companies embracing circular materials can capitalize on tax incentives and subsidies, enhancing their positioning in an increasingly competitive and sustainability-driven market. This adoption represents a strategic advantage, reinforcing their commitment to environmental stewardship while appealing to eco-conscious clients and regulatory bodies.

Yet, while the benefits of circular materials are significant, their integration introduces new challenges for Occupational Health and Safety (OHS) management. The inherent properties of circular materials often differ from traditional ones, requiring updates to safety protocols to mitigate potential hazards. For example, recycled materials might carry residual chemicals or unique compositions that

behave unpredictably under certain conditions, potentially posing risks to workers. Consequently, companies must proactively adjust their operational processes to address these emerging occupational risks. Investing in workforce training and developing material-specific safety procedures are vital steps to ensure that employees are fully aware of the unique characteristics and potential hazards of these materials. Such preparatory measures not only protect the workforce but also contribute to companies’ long-term competitiveness in a market that is increasingly scrutinizing the environmental and safety impacts of construction practices.

Moreover, this transition aligns with broader trends in industrial safety and environmental regulation. As regulatory frameworks evolve to incorporate sustainability metrics, the construction industry must adapt its OHS practices accordingly. The shift towards circular materials underscores the need for integrated risk management strategies that balance environmental sustainability with workplace safety. This dual focus ensures that the advantages of circular materials are fully realized while safeguarding workers’ health.

Hence, the construction industry’s shift towards CE, supported by the use of circular materials, marks a transformative step toward sustainability, with wide-reaching implications for economic efficiency, innovation, and competitive positioning. However, this shift also mandates a reevaluation of OHS practices to address the unique risks associated with circular materials. By proactively addressing these challenges, construction companies can align their operations with both environmental and occupational safety goals, ultimately creating a resilient and responsible sector poised to meet the demands of a sustainable future.

2. Theoretical Background

The construction industry is made up of many different groups of stakeholders, methods, and ways of thinking (Hart et al., 2019; Muñoz et al., 2007). The complexity of the sectorial construct is increased by the fact that the built environment consists of a wide range of different types of stock,

materials and processes, including infrastructure and buildings. CE concepts are gaining traction in the construction industry as a way to minimize waste generation and resource extraction. The construction sector is a major consumer of natural resources and producer of waste, so transitioning to a circular model is critical (Adams et al., 2017).

By implementing CE principles in construction, waste can be minimized through practices such as deconstruction, reusing materials, and recycling (Hossain et al., 2020; Verga & Khan, 2022). The decrease in waste automatically results in a safer work environment. If there is less trash and junk on construction sites, there is less chance of workers getting hurt, sick, or killed by falling objects, sharp edges, or toxic substances (Munaro & Tavares, 2021; Yu et al., 2022). Some authors (Arora et al., 2019; Eberhardt et al., 2019; Özçelikci et al., 2023) enhance the key relevance of broader strategic focus regarding the importance of circular materials as an innovation and sustainability booster.

However, many studies (Hossain & Ng, 2018; Khadim et al., 2023; Leising et al., 2018) found that while awareness of circular economy is growing, there is a lack of standardized practices and tools to help industry implement these concepts. More research is needed on developing business models that support circular materials, as well as overcoming technical, regulatory, and market barriers to reuse.

Circular materials, such as recycled plastics and composites, may behave differently under stress or release hazardous substances under certain conditions, which are not fully understood yet (Adams et al., 2017; Joensuu et al., 2020). Nowadays, the construction sector is the focus of two main types of publications: those that provide a comprehensive overview of the circularity of the sector as a whole (Benachio et al., 2020; Bilal et al., 2020; Çimen, 2021; Hart et al., 2019; Low et al., 2020), and others that examine certain strategies that lead to the circularity models related to the different stages of projects (design, construction, deconstruction) (Morel & Charef, 2019).

Other studies dive in the aspects of reuse of materials and components (Adams et al., 2017; Coppens et al., 2016; Yu et al., 2022), or on the reutilization of recycled building structure parts in new constructions (Shooshtarian et al., 2020). As well as research related to the management and treatment of the demolition waste (Ghisellini et al., 2018; Mahpour, 2018; Wahlström et al., 2020) and materials traceability emerge (Davari et al., 2023).

The adoption of CE principles in construction promotes the reduction of waste through strategies like deconstruction, reusing materials, and recycling. This reduction in waste inherently leads to a safer work environment (Chen, Feng & de Soto, 2022; Talla & McIlwaine, 2024). When fewer waste materials are generated and disposed of, there is less clutter, debris, and hazardous waste on construction sites, reducing the risk of accidents, injuries, and health

problems for workers (Illankoon & Vithanage, 2023; Munaro & Tavares, 2021; Yu et al., 2022). Integrating circular economy with lean construction principles could produce synergies and accelerate the adoption of circular materials in the built environment (Johns et al., 2023). Overall, the research shows the importance of circular materials in reducing the environmental impact of construction through strategies like reuse, design for disassembly, and material tracking (Saradara et al., 2024).

Tracking and confirming where, what, and how construction materials come from and change is called material traceability. Material traceability is crucial for identifying various risks in the context of CE (Nag, Sharma & Kumar, 2022). By understanding the source and makeup of materials, construction experts can recognize potential dangers, like harmful chemicals or unstable substances, which can endanger the well-being of workers.

3. Method

The exploratory literature review has been carried out with SPAR-4-SLR (Paul et al., 2021) to integrate the state of art on the CE in construction industry alongside the OHS approach to circular materials in general. Our method has also involved a comparative analysis of four construction companies (Table 1. Comparative case study participants 'profile.) that have integrated CE principles, specifically focusing on circular material use. Our research method shows that a small number of cases compared to each other can give us more useful and reliable information than studying each case separately (Newig & Fritsch, 2009) in particular in exploratory study. In examining the adequacy of a comparative case study for this research, the method's alignment with the study's objectives is apparent. This research focuses on understanding the impact of circular materials on OHS within the construction industry, emphasizing both the opportunities and risks posed by integrating CE principles into construction practices. A comparative case study approach allows for an in-depth, contextualized analysis across different instances, highlighting the variances in OHS outcomes associated with circular material usage across multiple companies.

The comparative case study is especially suitable for exploratory research in this area due to the relatively novel application of CE in construction and its impacts on OHS, as noted in the study. By analyzing a selected sample of construction companies implementing CE practices, the method provides a structured means of observing patterns and deviations across cases, rather than seeking universal or generalizable conclusions at this stage. This aligns well with the study's objective to uncover specific, context-dependent insights rather than broad statistical inferences. As stated in the document, the comparison of a few selected cases yields

Table 1. Comparative case study participants 'profile.

REF	GEOGRAPHIC RANGE OF CONSTRUCTION COMPANY	ANY TYPE OF CE STRATEGY IMPLEMENTED	NEW WORK PROCESSES TO DEAL WITH MATERIALS, RELATED TO CE IMPLEMENTED	MATERIALS TRACEABILITY IMPLEMENTED	N° OF WORKERS	SPECIFIC OHS MEASURES IMPLEMENTED TO FACE USE OF "CIRCULAR" MATERIALS
COMP1	NATION WIDE	YES	YES	YES	>1000	NO
COMP2	REGIONAL	YES	YES	NO	>400	YES
COMP3	NATION WIDE	YES	NO	NO	>800	YES
COMP4	INTERNATIONAL	YES	YES	YES	>5000	YES

Source: Own Elaboration.

more valuable and reliable information than isolated case analysis, especially in exploratory research of this kind.

Furthermore, the comparative case study method facilitates the examination of how each company handles the life cycle, traceability, and reuse of circular materials, aspects critical for understanding how CE principles specifically affect OHS. This focus on material life cycles and their management allows the study to assess the adequacy of existing safety protocols and explore the need for updated risk assessment tools and training programs tailored to the challenges presented by circular materials.

Ultimately, the comparative case study is well-suited to this research as it supports a comprehensive examination of the heterogeneous impact of CE adoption across different organizational settings within the construction sector. This method not only enhances the understanding of current OHS practices but also informs potential improvements by comparing diverse experiences and practices across cases.

Data collection includes interviews with project managers and OHS officers, alongside analysis of accident reports and safety audits. The objective is to identify correlations between the level of circular material use and variations in OHS effectiveness across the projects. Each case study documents the project's approach to circular materials use and their traceability, detailing the origin, life cycle, and reuse of materials. Data collection in this research involves qualitative interviews with project managers and OHS officers, alongside quantitative analysis of safety reports, accident records, and safety audits. This mixed-methods approach enriches the comparative analysis by integrating both subjective perspectives on circular materials' impact on OHS and objective records of OHS performance. By investigating correlations between circular material adoption levels and changes in safety outcomes, this approach not only illustrates causative factors but also uncovers gaps in current safety management practices. The study assesses OHS performance by examining the frequency and severity of safety incidents and overall safety outcomes.

4. Findings

With a growing awareness of the CE principles in the construction industry, an increasing number of firms are recognizing the potential strategic advantages of adopting novel materials and sustainable practices. The CE model, emphasizing the reduction, reuse, and recycling of materials, represents a significant shift from traditional, linear methods of resource consumption to a more regenerative approach. For construction companies, embracing CE principles not only distinguishes them in a competitive market but also positions them at the forefront of sustainable innovation, appealing to environmentally-conscious clients and regulators. The adoption of CE practices holds promise for reduced waste generation, enhanced material efficiency, and lower environmental impacts, aligning construction practices with global sustainability goals. With an increasing number of construction firms recognizing the potential of CE, the sector is eyeing the adoption of novel materials as a strategic advantage. Embracing CE principles not only distinguishes companies in a competitive market but also positions them at the forefront of sustainable innovation.

Implementing CE principles in construction involves strategies like Life Cycle Assessment (LCA), Construction and Demolition Waste (CDW) management, End-of-Life (EoL) planning, Design for Disassembly (DfD), and Building Information Modeling (BIM). These approaches offer tools to optimize material use, facilitate better traceability, and improve Occupational Health and Safety (OHS) standards within the industry. LCA, for instance, assesses environmental impacts throughout a product's life cycle, providing valuable insights into areas where resource efficiency can be improved. By managing CDW effectively, companies can divert significant amounts of waste from landfills, repurposing it within new projects or directing it toward secondary markets. EoL strategies and DfD support dismantling buildings in a way that retains the material value, allowing for easier recovery and reuse, while BIM technology enhances collaborative planning, integrating CE

considerations from the design phase onward. These tools not only contribute to material traceability and sustainable use but also reinforce safety standards by promoting a cleaner and less hazardous working environment.

The growing interest in CE across the construction sector stems from both environmental incentives and the opportunities presented by emerging materials. This shift is not merely ideological but increasingly seen as a practical business advantage. The adoption of innovative materials such as self-healing concrete, bio-based compounds, and recycled plastic bricks brings substantial benefits, including improved performance, reduced reliance on non-renewable resources, and cost savings over time. Self-healing concrete, for instance, can autonomously repair small cracks, reducing the need for maintenance and extending the material's lifespan. Similarly, bio-based materials and composites created from recycled plastic offer robust performance and resource efficiency, providing a durable and energy-efficient alternative to conventional materials. This exploration and adoption of new materials is central to the construction industry's shift towards CE, as these alternatives support a departure from resource-intensive traditional building methods, paving the way for structures that are more sustainable, durable, and less costly in the long term.

However, the integration of circular materials introduces unique challenges, particularly in terms of OHS. As companies incorporate recycled or repurposed materials, new health risks arise, often stemming from the unfamiliar chemical compositions or physical properties of these materials. For instance, dust generated from cutting or handling recycled components can differ chemically from traditional materials, potentially requiring new risk assessments and specific safety measures. This "silent threat" underscores a gap in the current understanding of how innovative circular materials interact with workplace safety. Without adequate knowledge and protocols, these materials could expose workers to unanticipated hazards, making the alignment of CE practices with OHS frameworks a critical concern for the industry. Only larger, nationwide companies are generally able to implement comprehensive circular work processes that integrate materials traceability with a well-defined OHS strategy, underscoring the need for broader access to resources and guidelines for smaller firms also aiming to adopt CE principles.

Thus, the implementation of these circular materials brings recognizable new challenges for the management of occupational risks. The handling, processing and application of recycled or reused materials may introduce non-traditional occupational hazards that require a review and adaptation of SSL practices. For example, "*dust generated by cutting recycled materials may have chemical compositions different from that of new materials, which could require new risk assessments and specific mitigation methods*" [Comp3].

To effectively manage these new occupational risks, the handling, processing, and application of circular materials demand an adaptation of safety protocols. New and specific training is essential, as identified by the companies analyzed in the study. Employees need to be fully informed about the properties of circular materials and the health implications of their use, enabling them to adopt appropriate safety practices. This can include the development of advanced training programs to educate workers on the specific risks associated with recycled and reused materials, such as the potential release of hazardous substances during material processing. Additionally, safety equipment and protective gear may need to be updated or redesigned to suit the unique properties of these materials. For example, "*respirators designed for traditional construction dust might not offer adequate protection against the different particle sizes or chemical profiles present in recycled material dust.*" [Comp4].

Investment in advanced training and updated safety equipment is an imperative step for companies committed to CE. This training should emphasize both practical handling techniques and an understanding of the broader implications of material use, as it pertains to both personal health and overall workplace safety. With the correct precautions and knowledge in place, companies can safely incorporate CE materials into their projects without compromising worker health or safety. Effective training also strengthens the company's competitive position, as well-trained employees are better equipped to manage risks, thus reducing the likelihood of workplace accidents and enhancing productivity. "*[...] There are already difficulties in effectively raising awareness and training workers on handling materials from different sources. With circular materials, it may be necessary to develop parallel plans for tasks or roles that are primarily exposed to recycled or reused materials if these do not meet the standards of more "conventional" materials.*" [Comp3].

Beyond the immediate benefits for worker safety, CE adoption offers substantial economic advantages for construction firms. Reusing and recycling materials allows companies to reduce both purchasing and disposal costs, strengthening their supply chains against market fluctuations and potential resource scarcity. By integrating CE principles, construction companies not only achieve cost savings but also build resilience, reducing dependence on finite resources and enhancing operational efficiency. The CE not only promises to reduce the environmental impact of construction, but also offers considerable potential to revolutionize the sector in terms of efficiency and economic sustainability. Reusing and recycling materials allows companies to reduce purchasing and disposal costs, while strengthening the supply chain against market fluctuations and resource scarcity, however "*decision-making instruments to establish optimal processes of OHS on the new*

material implementation's basis are still lacking" [Comp1]. In a market increasingly defined by resource limitations and regulatory pressures, this resilience is a valuable asset, positioning companies to meet both current and future demands. However, a significant challenge remains: decision-making instruments tailored to optimize OHS within the context of CE material implementation are still lacking. The absence of comprehensive guidelines and standardized protocols limits the ability of firms to seamlessly integrate OHS considerations with CE objectives, creating a barrier to wider adoption within the industry.

All things considered, the CE framework presents a promising avenue for the construction sector, offering pathways to reduce environmental impact and improve economic sustainability. The four companies agreed, although some clarified specific aspects. *"The impact of circular materials and components on OHS will depend on the strategic importance of these materials for operating costs and their relevance to the company's sustainability policies. Without this consideration, it will not be worthwhile to establish different OHS models"* [Comp4]. *"The impact on OHS will primarily depend on the effect on costs and overall productivity. This will not be a CSR decision; it will be a decision driven by an analysis of the income statement"* [Comp1]. *"The company will decide on the use of circular materials based on their regulatory compliance and efficiency. OHS will then need to adapt accordingly"* [Comp2]. By embracing circular materials and sustainable processes, the industry can mitigate resource depletion, lower greenhouse gas emissions, and minimize waste. However, this transition also brings new challenges in terms of OHS, particularly due to the unfamiliar risks associated with innovative circular materials. The implementation of CE practices necessitates proactive risk management and a commitment to continuous learning, as new materials and methods emerge.

5. Theoretical and practical implications

This study holds significant theoretical and practical implications for both the construction industry and OHS frameworks. Theoretically, the research expands on existing literature by addressing the relatively unexplored nexus between CE principles and OHS, specifically within construction. This intersection is critical as CE principles, which emphasize resource efficiency through reuse and recycling, inherently modify traditional construction processes and material compositions, leading to unique occupational risks. By investigating circular materials' specific properties—such as recycled plastics and innovative composites—this study highlights the need for updated safety protocols that account for the novel behaviors and potential hazards these materials may introduce under different operational conditions. Thus, the findings contribute to a foundational under-

standing of the complexities in aligning CE practices with existing OHS structures, proposing a reevaluation of safety models in light of sustainable innovation.

Practically, the study underscores actionable priorities for construction managers, safety officers, and policymakers. For construction managers, adopting CE practices offers a pathway to sustainability, yet requires substantial investment in workforce training on the unique characteristics of circular materials. The findings suggest that a lack of understanding of these materials could lead to safety risks, necessitating the development of specialized training programs that equip workers to handle recycled components safely. For OHS officers, the research points to the necessity of revising traditional risk assessments and personal protective equipment (PPE) standards to address the varied and potentially hazardous nature of circular materials, such as differing dust particulates that may arise during material handling.

Moreover, the study provides guidance for policymakers on the importance of regulatory updates that facilitate CE adoption while ensuring robust worker protections. This includes the establishment of guidelines for materials traceability, which enhances the ability to identify and mitigate risks associated with material origins and life cycles. Ultimately, the research advocates for policies that balance environmental objectives with OHS standards, ensuring that CE adoption within construction contributes not only to environmental goals but also to enhanced worker safety. Through this dual focus on sustainability and safety, the construction industry is positioned to foster resilience, ensuring that its shift toward CE not only addresses resource efficiency but also meets the pressing need for a safer, more responsible work environment.

5.1. Limitations and guidelines for future research

While this study offers valuable insights into the impact of CE practices on OHS in the construction industry, several limitations should be considered when interpreting the results. First, the study relies on a relatively small sample size, drawing primarily from a limited number of companies actively implementing CE practices within a specific geographic region. This narrow scope may impact the generalizability of the findings, as the regulatory frameworks, resource availability, and OHS challenges specific to this region could influence outcomes. Future research should consider expanding the geographic and organizational diversity of the sample to capture a broader range of CE implementation contexts. Comparative studies across different countries or regions would offer a more comprehensive perspective, allowing for the analysis of varied regulatory and industry-specific factors that may affect the integration of CE and OHS.

Additionally, this research predominantly employs qualitative methods, including interviews and case studies, which, while beneficial for exploratory analysis, may introduce subjective biases. Relying on qualitative data alone may limit the robustness of conclusions, particularly given the complexity of assessing material-specific safety impacts. Future studies could incorporate quantitative approaches, such as longitudinal surveys or experimental studies, to measure the direct correlation between CE practices and OHS outcomes more precisely. A mixed-methods approach could also offer a more nuanced understanding, allowing researchers to triangulate qualitative insights with quantitative data to validate and strengthen findings. The study's focus on OHS practices primarily examines physical risks associated with circular materials, such as chemical exposure and dust from recycled materials. However, it does not fully address the potential psychological and ergonomic impacts of CE practices on workers. For instance, adapting to new materials and procedures may involve a learning curve that could increase cognitive load, stress, or fatigue among workers. Future research could benefit from a holistic approach that includes the psychological and ergonomic dimensions of OHS, providing a more comprehensive view of worker well-being in the context of CE.

Another limitation relates to the evolving nature of CE materials and technologies, as they continue to advance rapidly. The safety implications of certain circular materials—such as composites or bio-based alternatives—are not yet fully understood, and new materials are consistently introduced to the market. Longitudinal studies could address this limitation by examining how the risks and benefits associated with CE materials evolve over time, capturing the long-term effects of sustained CE adoption on OHS. Moreover, experimental research into specific material types under various conditions (e.g., temperature, wear, and chemical exposure) could yield valuable insights into the full spectrum of risks. Finally, the study calls for further research on regulatory adaptations and policy support needed to facilitate the integration of CE and OHS frameworks. As governments increasingly prioritize sustainability, future research should investigate the effectiveness of emerging regulatory guidelines in managing CE-related OHS risks. Cross-sectoral analyses, comparing construction with other industries undergoing CE transitions, would also provide insights into best practices and regulatory models that could be adapted to the construction sector.

In summary, while this study advances understanding of the relationship between CE practices and OHS in construction, future research should aim to broaden the sample scope, diversify methodological approaches, explore comprehensive OHS impacts, and address the evolving nature of CE technologies and materials. These guidelines would enhance the robustness and applicability of future findings,

supporting the construction industry's shift toward a safer, more sustainable future.

6. Conclusions

The construction industry's shift toward the CE marks a transformative era, emphasizing the use of innovative materials and sustainable practices that aim to reduce resource consumption and waste production. This pivot is largely driven by the adoption of advanced materials such as self-healing concrete, bio-based materials, and bricks made from recycled plastics. These materials bring substantial environmental benefits, such as lower emissions and decreased reliance on virgin resources, while simultaneously enhancing construction performance. For example, self-healing concrete can autonomously repair small cracks, thereby reducing maintenance needs and extending the lifespan of structures. Similarly, bio-based materials and recycled components offer durability and efficiency, representing a major shift away from traditional construction methods. This evolution reflects a profound commitment to sustainability, positioning the industry to deliver structures that are resilient, energy-efficient, and less resource-dependent. This transition showcases the sector's capability to innovate, adapting its practices and materials to meet the growing demands for sustainable development and climate resilience.

The influence of CE on OHS in construction is both substantial and essential to consider. As CE principles are integrated, they not only contribute to environmental protection but also introduce potential safety benefits, leading to a more sustainable and secure industry. Employing circular materials in construction requires transparency throughout the supply chain to ensure safe handling and usage. A deeper understanding of these materials' characteristics and associated risks is crucial for both OHS officers and the workforce, as unfamiliar properties may introduce new hazards. For example, recycled materials may contain residual chemicals or unique particulate compositions that behave differently from virgin materials under stress. Awareness of these differences is necessary for implementing adequate protective measures and adapting training protocols. Therefore, increasing worker knowledge through targeted training is fundamental, as it fosters a safer work environment and ensures that safety measures are suited to the properties of circular materials.

The proactive risk management approach fostered by CE practices is especially pertinent in the construction industry. Transitioning to circular materials involves challenges for OHS because these materials may not align with existing safety protocols designed for conventional materials. For instance, handling recycled components may necessitate a reevaluation of dust control practices and respiratory

protection due to differences in particulate matter composition. This necessitates a comprehensive review of safety protocols, risk assessments, and personal protective equipment (PPE) requirements to cover all potential hazards posed by circular materials. Moreover, regulatory compliance remains a dynamic challenge, as industry standards and regulations often lag behind rapid technological and material advancements. This regulatory gap creates periods of uncertainty, during which companies may face difficulties aligning their OHS practices with the latest CE technologies while remaining compliant with established safety standards. A more agile regulatory framework that can keep pace with these advancements is therefore essential to ensure that worker safety is not compromised during this transitional phase.

Equally important, integrating circular materials often requires new or modified safety equipment and procedures. Traditional protective gear and handling tools may not be suitable for newer, recycled alternatives, as these materials might necessitate specific adaptations in handling methods. For instance, traditional tools and equipment may not be designed to accommodate the structural variances or stress responses of recycled or repurposed materials. This shift calls for an investment in new safety technologies and tools tailored to circular materials, as well as an adjustment in safety protocols to address these unique requirements effectively. Construction firms adopting CE practices should be prepared to invest in these changes, which, although requiring initial resource commitment, ultimately contribute to safer work environments and improved operational efficiency.

In closing, the construction industry's commitment to CE principles, emphasizing safer working conditions and sustainable material use, has the potential to redefine its approach to both sustainability and competitiveness. By embracing circular materials and processes, the industry is better equipped to address resource scarcity, reduce environmental impact, and enhance worker safety. However, realizing these benefits requires a proactive, integrative approach to OHS that anticipates the distinct risks associated with circular materials. This entails updating risk assessments, investing in suitable PPE and equipment, and fostering regulatory support that can evolve with technological advancements. Such strategies not only protect workers but also align the construction sector with global sustainability goals, reinforcing its role in building a resilient, future-ready economy. Through these combined efforts, the construction industry can navigate the complex demands of sustainability and safety, ensuring it remains competitive and adaptable in an era of rapid environmental and regulatory change.

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